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THE VARIATION OF RESISTANCES WITH ATMOSPHERIC HUMIDITY.[1]

By E. B. Rosa and H. D. Babcock.

It has long been known that manganin resistances prepared in the manner developed by the Physikalisch-Technische Reichsanstalt do not remain entirely constant in value, but that appreciable differences sometimes occur among a group of apparently exactly similar coils. These variations are usually very small or inappreciable with coils of 0.1 ohm and 1.0 ohm; but with coils of 10, 100, 1,000 ohms and higher values the variations are often so considerable that when used for precision work it has been found necessary at the Bureau of Standards to determine their values by stepping up frequently from the 1-ohm standards. These variations have been found to be greater in England than in Germany, and it has been suggested that the difference may be due to some difference in the methods of preparation of the coils followed in England and in Germany.[2] At the Bureau of Standards the variations in the values of manganin resistances have been a source of great annoyance, and they have been found to be as great in the resistances made by the best German makers as in those made in America. These variations occur in the most carefully prepared standards of the Reichsanstalt form, as well as in the resistances of Wheatstone bridges, potentiometers, resistance boxes, etc.

SEASONAL CHANGES OF RESISTANCE.

In the course of an extended investigation[3] at the Bureau of Standards on the ratio of the electromagnetic to the electrostatic unit of electricity it was found that all the resistances employed

[1] Paper read before the American Physical Society at Washington, April 21, 1907. A preliminary account of this work appeared in the Electrical World of June 29, 1907, and in the London Electrician, June 14, 1907.

[2] Report of Prof. R. T. Glazebrook, Director of the National Physical Laboratory, *Engineering* (London), March 22 and April 5, 1907.

[3] By E. B. Rosa and N. E. Dorsey; this Bulletin, **3**, p. 433, 1907.

had a higher value at the same temperature in summer than in winter, the change being a gradual drift upward from early spring to midsummer, followed by a steady drift back to the same minimum in the winter. The amplitude of the change was of course small, varying from 15 to 25 parts in 100,000, but was far too large to be neglected in precision work. Most of these resistances were kept submerged in oil all the time, but some were in air. In all cases the temperatures were taken and the resistance measurements made with great care.

The possibility of these changes being due to atmospheric humidity suggested itself, but it was not at first evident how an increase of resistance could be produced by an increase of humidity. The effect of leakage arising from moisture deposited on the coils or upon the tops of resistance boxes is of course to *decrease* the resistance, and this effect would increase with the humidity. In order to ascertain the cause of the marked change in the opposite direction, to determine its magnitude, and to find how to prevent it, we took up last November a systematic study of the question.

It was very soon found that changes such as occurred during an interval of six months in the atmosphere of the laboratory could be induced in a few days by placing the resistances in a closed case in which an atmosphere of high humidity was maintained, although it usually required several weeks for the resistance of a coil to reach a maximum, or to return to its former value when restored to the original conditions of humidity.

Two apparatus cases were employed, the atmosphere within one being kept at a nearly constant relative humidity of about 25 per cent, the other being kept at higher humidities, ranging from 40 to 100 per cent, although seldom higher than 80, and oftenest about 60 per cent. Each case was provided with thermometers and recording hygrometers, the latter being frequently calibrated by aspiration psychrometers.

The lower humidities were maintained by keeping calcium chloride in the apparatus cases, varying the quantity exposed according to the humidity desired. The higher humidities were obtained by exposing a greater or less surface of water in open vessels, and running a very small electric fan to circulate the air within the case. The records of humidities and temperatures were taken continuously through twenty-four hours, and comparatively small

fluctuations occurred except those produced by intentional changes of the conditions.

The higher resistances were measured generally to one or two parts in a million, and corrections made for small fluctuations in temperature. All measurements were finally referred to the standard of the Bureau determined by the mean value of a number of one-ohm and tenth-ohm coils. The changes in the resistances of the latter are known to be relatively small.

CHANGES ARE DUE TO MOISTURE ABSORBED BY SHELLAC.

The cause of the increase in resistance of the manganin coils, the wire of which is embedded in a heavy covering of shellac thoroughly dried out by baking, is that *the shellac absorbs moisture from the surrounding atmosphere and expands, stretching the manganin wire and thereby increasing its resistance.* The amount of moisture absorbed depends on the relative humidity of the atmosphere, the moisture in the shellac gradually coming to equilibrium with the moisture outside when any given humidity is maintained constant. When the atmosphere is drier the shellac gives up moisture and shrinks, and the wire also contracts and its resistance decreases. The resistance therefore is constantly changing with changes in atmospheric humidity, and is a constant only when the atmospheric humidity is constant or when the coil is sealed so that moisture can not get into the shellac. *Dipping the coils in melted paraffin* will seal them effectually against moisture, so that even the finest wire, such as is used in coils of 1,000 and 10,000 ohms, remains of constant resistance. *Sealing such a coil in a test tube* will keep its resistance constant, even though it had previously been exposed to a moist atmosphere. *Submerging the coils in oil does not protect the shellac from atmospheric humidity*, as the oil absorbs moisture and transmits it to the coils. Hence submerged coils increase in resistance when the atmospheric humidity increases, and decrease in resistance when the humidity decreases. The oil retards the change of resistance and decreases the amplitude somewhat, but still permits considerable changes to occur, especially in the higher resistances.

A change of resistance of 25 parts in 100,000 will be produced by an increase in length of the wire of 12.5 parts in 100,000. If the wire is wound on a spool 4 cm in diameter (the size used in a Wolff

standard of the Reichsanstalt form) the diameter must be increased by the swelling of the shellac by 0.0005 cm or 5 microns. This is of course an appreciable increase in diameter, although much more difficult to measure than the change in resistance. Coils sealed by a covering of paraffin will remain constant for months through wide fluctuations of moisture, certainly to within a few parts in a million, which indicates that the diameter has not changed during that time by as much as 0.2μ, if at all. We shall presently give evidence to show that manganin wire of all sizes is remarkably constant in resistance, and that changes that have been attributed to the manganin are due to the shellac in which it is embedded.

In Fig. 1 are given curves showing the seasonal changes of certain resistances during the past two years. These curves, which were plotted by Dr. Dorsey in the investigation referred to, prompted this study of the variation of resistances with humidity. The curves showed conclusively, what had probably never before been suspected, that the resistance of a shellac-covered manganin coil is greater in summer, at a given temperature, than in winter, at least under some conditions. These resistances were exposed only to the atmosphere of the laboratory, and in summer the humidity was kept lower than normal during 6 or 8 hours of nearly every working day by means of cold brine coils in the room, which condensed moisture upon them. The object of thus reducing the humidity was to secure more perfect insulation than could be obtained otherwise. This is especially necessary in the measurement of small capacities, where large resistances are employed and slight leakage is serious. The changes in resistances were therefore appreciably less than would have occurred normally. All resistance measurements were made in an atmosphere dry enough to give thoroughly satisfactory insulation.

It is possible that the greater changes observed in England than in Germany in manganin coils that have been shellacked are due to greater ranges in the atmospheric humidity in England. That some English makers have reported no appreciable changes in their manganin resistances is probably explained by their use of paraffin for insulation instead of shellac.

Fig. 2 shows the changes in certain manganin resistances when subjected to variations in atmospheric humidity, the values of the humidity, the dates and the variations in resistance being shown in

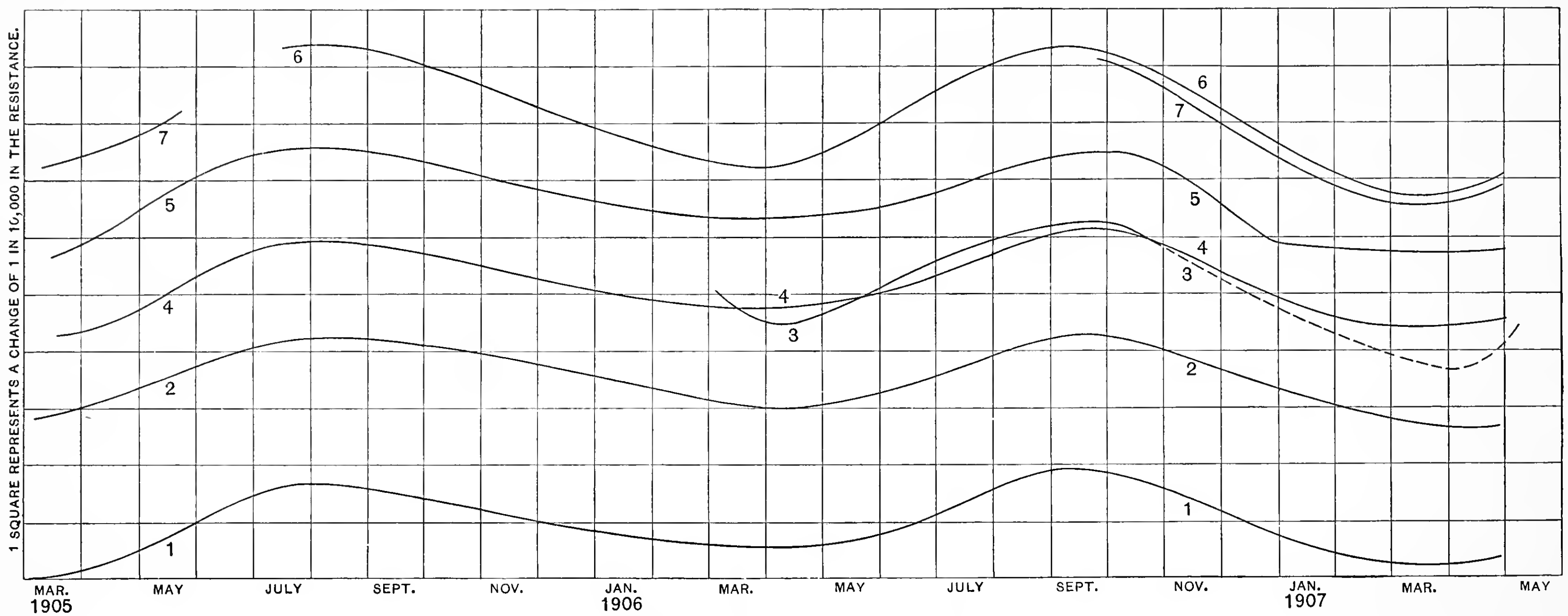

Fig. 1.—*Variation of resistance due to seasonal changes.*

The curves of Fig. 1 show seasonal changes of manganin resistance due to varying atmospheric humidity. Observations extended through two years and two months. Resistances always in laboratory atmosphere. All resistances were of usual construction and were made by Otto Wolff. One vertical space is 1 part in 10,000 in resistance.

Curve 1 is 1,000-ohm coil submerged in oil from resistance box No. 2470.

Curve 2 is 1,000-ohm coil submerged in oil from resistance box No. 2471.

Curve 3 is 1,000-ohm coil in air from resistance box No. 3087.

Curve 4 is Σ1,000-ohm coil in oil from resistance box No. 2470.

Curve 5 is Σ1,000-ohm coil in oil from resistance box No. 2471.

Curve 6 is mean of 9 coils each of 10,000 ohms in oil from resistance box No. 2620.

Curve 7 is mean of 9 coils each of 10,000 ohms in air from resistance box No. 2621.

Σ1,000 indicates 1,000 ohms made up of coils 500+200+200+100. There is no record of the values of the resistance for curve 7 between May, 1905, and September, 1906.

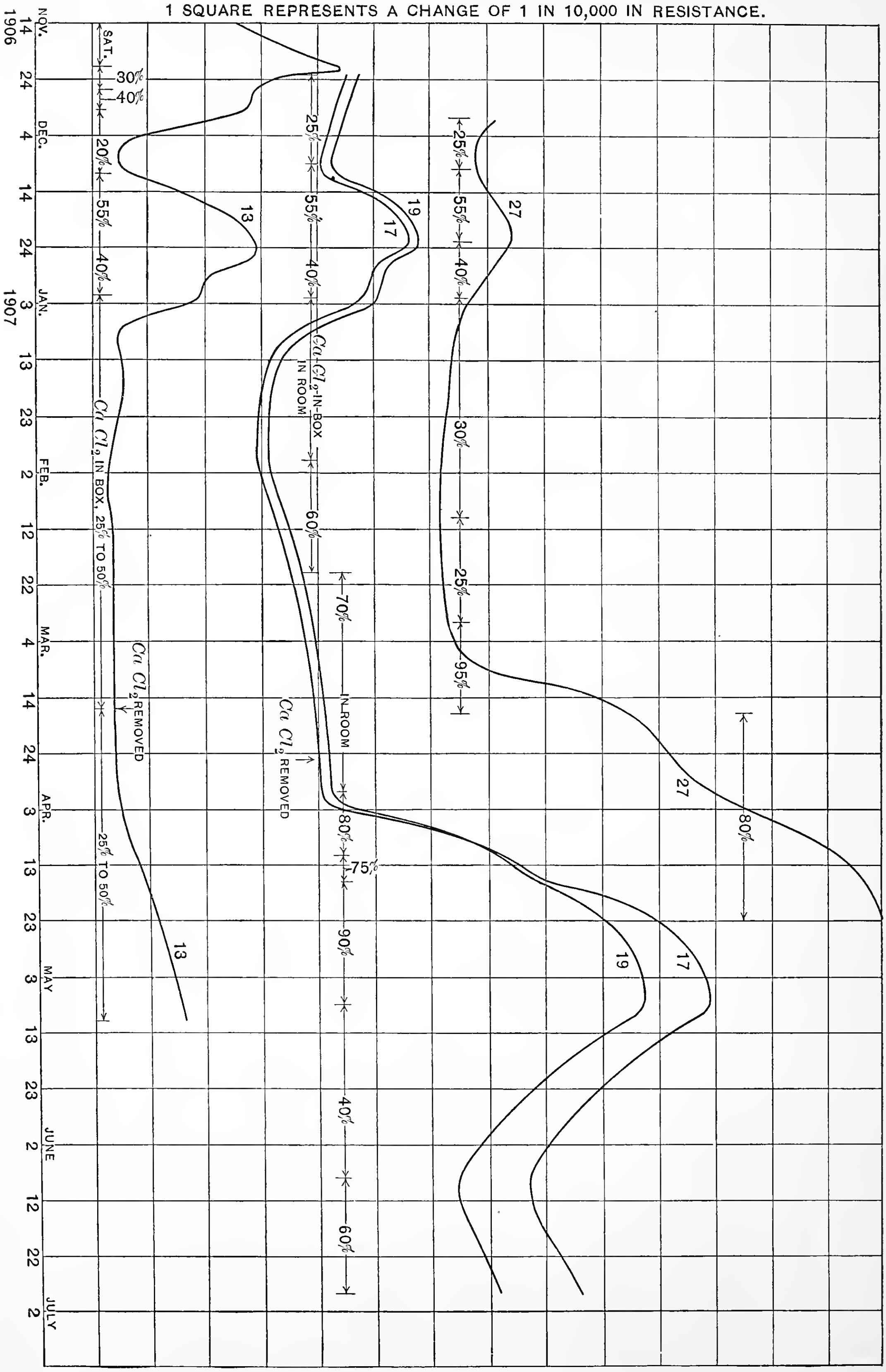

Fig. 2.—*Changes of resistance due to atmospheric humidity.*
(For explanation of curves see opposite page.)

the curves. The 1000-ohm coil represented by curve 13 was first placed for a few days in a saturated atmosphere. The change in resistance was very rapid, but was suddenly stopped by reducing the humidity to 30 per cent. A sudden drop in resistance followed, the rate of decrease being reduced by raising the humidity for a few days to 40 per cent. The rate of decrease was again augmented by reducing the humidity to 20 per cent. After the resistance had decreased to a point below its initial value, the humidity was increased to 55 per cent, when the resistance rose as shown and then fell when the humidity was reduced to 40 per cent. The change in resistance between the maximum value of November 22 and the minimum value of December 7 was 40 parts in 100,000. On January 2 a quantity of calcium chloride was placed in the bottom of the resistance box, which was closed up as nearly air-tight as practicable without sealing. The resistance fell rapidly for a few days (about 15 parts in 100,000) and then remained nearly constant for three months, but was not entirely independent of changes in room humidity. The higher average humidity of April caused the resistance to rise appreciably.

Curves 17 and 19 show how closely the 1000 coil and the $\Sigma 1000$ (made up of coils of $500+200+100+100+\Sigma 100$) vary together as the humidity is varied. In this case also $CaCl_2$ was added to the box on January 2, resulting in a decrease in resistance. When the box was placed in an atmosphere of 60 and 70 per cent humidity the resistance rose appreciably in spite of the $CaCl_2$. After the calcium chloride was removed the box was put in the damp case and the resistances rose rapidly, and then decreased when the humidity was reduced to 40 per cent, and then increased again with a humidity of 60 per cent.

Explanation of curves of Fig. 2, p. 126.

The curves of Fig. 2 show variations in manganin resistances due to changes in atmospheric humidity. Resistances kept in an inclosed space where the humidity was under control. Observations extended through eight months. The relative humidities are indicated on the curves. One vertical space is 1 part in 10,000 in resistance.

Curve 13 is 1,000-ohm coil in air from Wolff box No. 3087. (Same coil as No. 3 of Fig. 1.) Curve 17 is 1,000-ohm coil in air from Wolff box No. 3080. Curve 19 is $\Sigma 1$,000-ohm coil in air from Wolff box No. 3080. Curve 27 is 1,000-ohm coil in air made by the Leeds and Northrup Company.

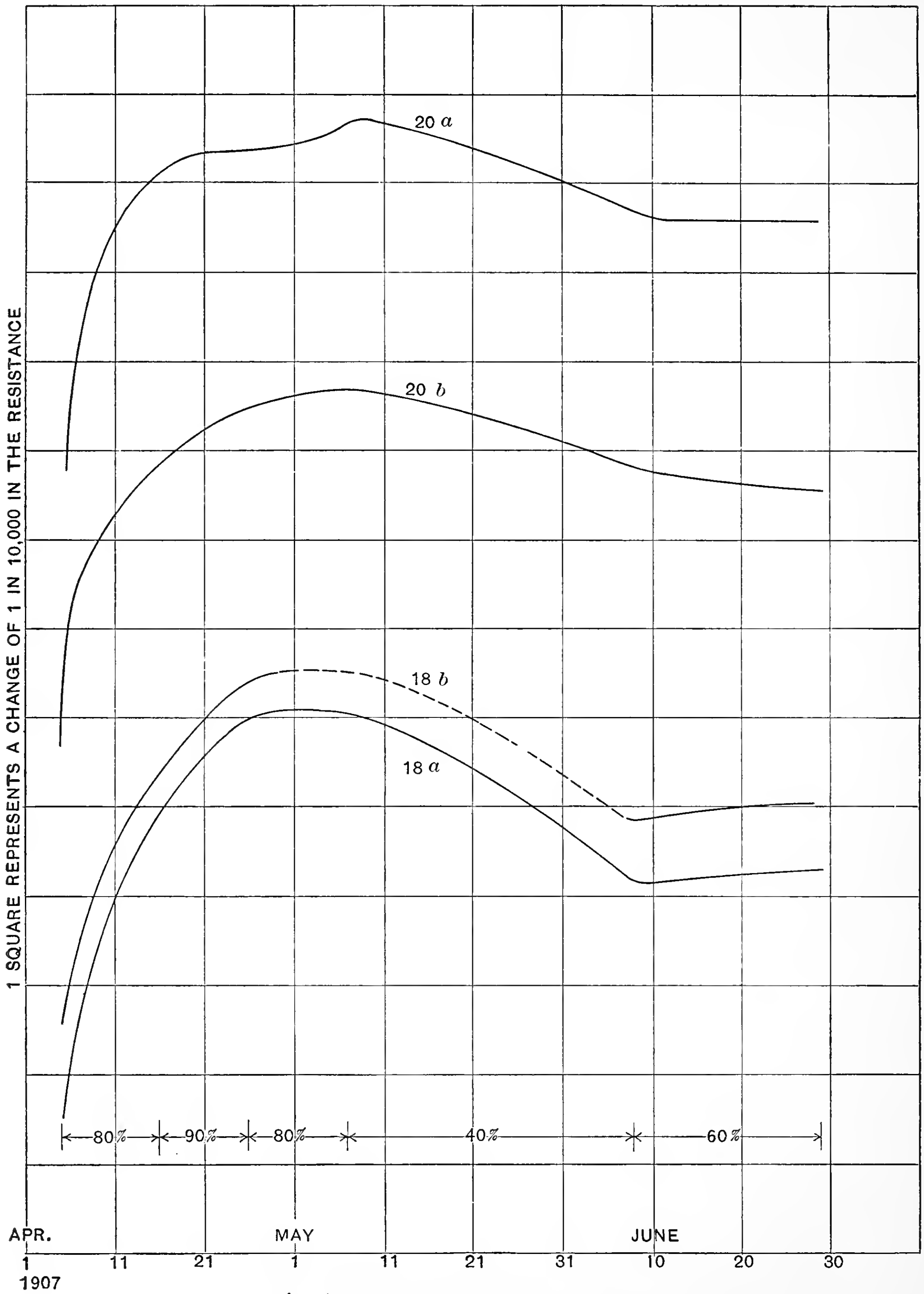

Fig. 3.—*Changes of resistance of coils.*

The curves of Fig. 3 show changes in resistance of manganin coils of 10 and 100 ohms.

Curves 18a and 18b are two coils of 100 ohms each in air, Wolff box No. 3080.

Curves 20a and 20b are two coils of 10 ohms each in air, Wolff box No. 3080.

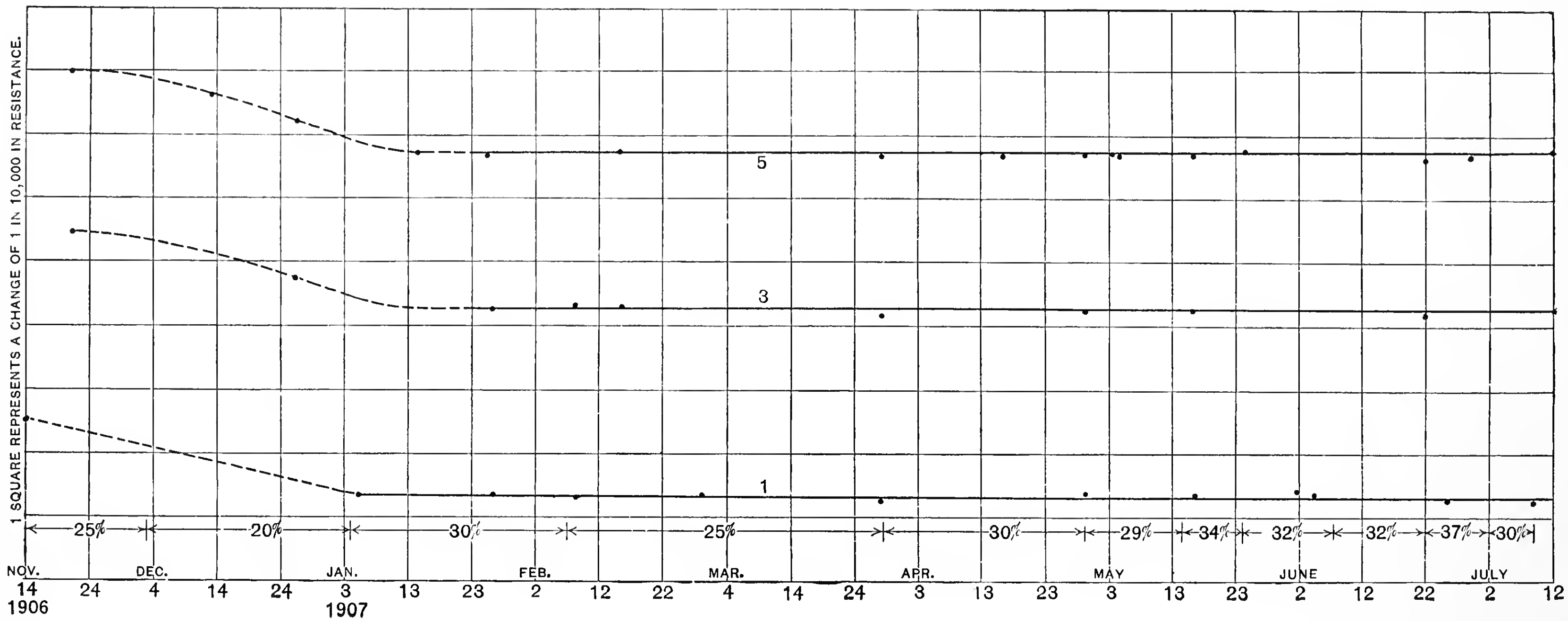

Fig. 4.—*Resistances of coils in oil. Humidity nearly constant.*

The curves of Fig. 4 show how slight are the variations of resistance of manganin coils submerged in oil when kept at very nearly constant humidity. All these coils were from Wolff box No. 2471. No. 1 of this series is the same coil as No. 5 of Fig. 1.

Curve 1 is $\Sigma 1,000$ ohms, curve 5 is 10,000 ohms, curve 3 is $\Sigma 10,000$ ohms; all in oil at a nearly constant humidity of 25 to 30 per cent.

Curve 27 represents a shellacked manganin coil made by the Leeds and Northrup Company, showing large changes in resistance as the humidity is varied.

Fig. 3 shows that the changes in coils of heavier wire, as used in resistances of 10 and 100 ohms, are very considerable, amounting to 35 to 50 parts in 100,000, due to 80 per cent humidity.

Fig. 4 shows three resistances from Wolff box No. 2471 (all in oil), which have been kept for several months at as nearly constant humidity as possible and which have remained remarkably constant in value. Curve 1 represents the same set of coils (Σ1,000) as curve 5 of Fig. 1. During November and December it gradually decreased in value, coming to an equilibrium value for approximately 25 per cent humidity about January 1. Between January 1 and July 9 this coil changed only a few parts in 1,000,000, having come down to a minimum value in March. The average humidity in the case has been a little higher since March, and this probably accounts for the slight increase in resistance. Curve 5 represents a single spool coil of 10,000 ohms, and curve 3 represents the Σ10,000 coils of the same box. These three curves are practically horizontal, all showing a minimum in March a few parts in a million less than the values in January and since April, the drop in January and February being doubtless due, as stated above, to the continued drying out of the oil, and the rise in April to a slightly higher humidity in the case, due to higher humidity in the room, the case not being entirely tight.

Fig. 5 shows three curves, all representing resistance standards of the Reichsanstalt form. Curve 7 is a 1,000-ohm standard (No. 3039) kept totally submerged in oil in a space at nearly constant humidity of 25 to 30 per cent from January 4 to March 28, the resistance decreasing slowly during that period, as the oil dried out gradually. From March 28 to April 16 the coil, still submerged in the same oil, was in a case at approximately 80 per cent humidity, and the resistance rose about 17 parts in 100,000. The humidity was then reduced to about 25 per cent and the resistance fell off 11 parts in 100,000 in the same time that it rose 17 parts. This shows how great a change can take place in a coil kept submerged in pure petroleum oil, when the humidity of the atmosphere changes. Since June 25 this coil has been in the atmosphere of the laboratory, not

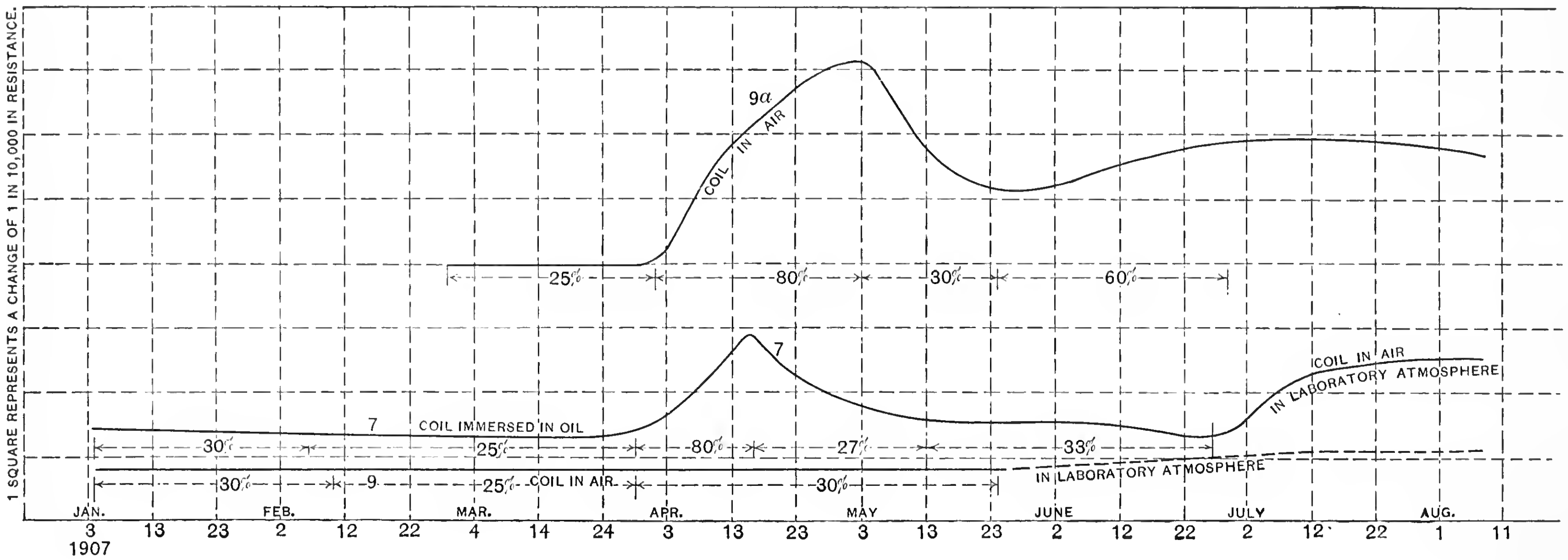

Fig. 5.—*Difference in behavior of coils.*

The curves of Fig. 5 show the difference in behavior between Wolff standard coils (Reichsanstalt form) when kept at constant humidity and when in an atmosphere of varying humidity.

Curve 7 is standard coil of 1,000 ohms submerged in oil, No. 3039.

Curve 9 is standard coil of 10,000 ohms in air, No. 1392.

These two coils were maintained at nearly constant humidity until March 26, when 7 was placed in an atmosphere of 80 per cent humidity until April 16, when it was restored to the drier chamber.

Curve 9a is standard coil of 10,000 ohms in air, No. 3040.

in oil, and has increased in resistance about 13 parts in 100,000. Curve 9 is a standard 10,000-ohm coil (No. 1392) kept in air at a nearly constant humidity of 25 to 30 per cent from January 4 to May 24. Its changes are very slight, showing a small decrease at first, corresponding to the coils in oil. Since May 24 this coil has been in the atmosphere of the laboratory and has gradually increased in value. Curve 9*a* represents another 10,000-ohm standard (No. 3040) in air at different humidities, showing, in marked contrast to curve 9, large changes due to variation of humidity. Curve 11, Fig. 5*a*, represents a 1,000-ohm standard (No. 3057) in air at different humidities. The fluctuations in the resistance of the latter amount to about 35 parts in 100,000 between the minimum and the

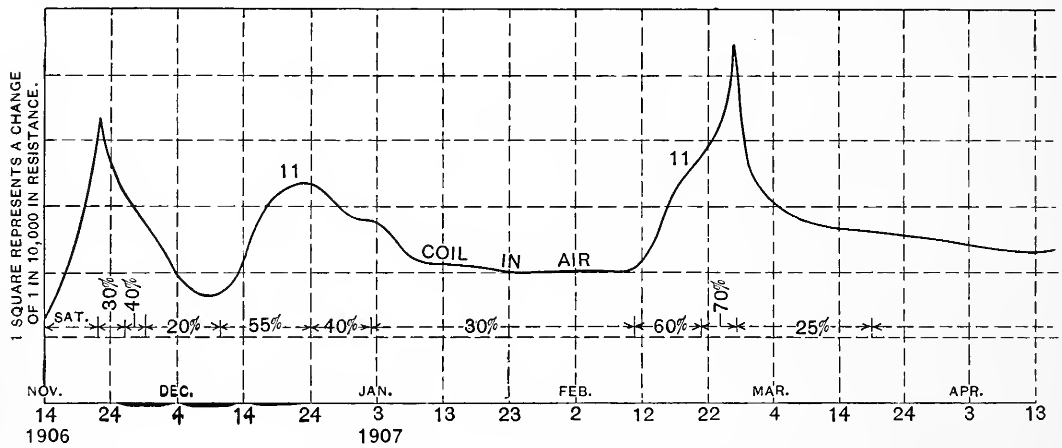

Fig. 5a.—*Behavior of Wolff standard coil.*

Curve 11 is a standard coil, No. 3057, of 1,000 ohms in air, at varying humidities.

Explanation of curves of Fig. 6, p. 133.

The curves of Fig. 6 show the differences in the behavior of resistances of manganin coils, all of which were wound on wood spools and kept in an atmosphere of different humidities, but with different methods of preparation or of mounting.

Curve 55, 1,000 ohms, wood spool thoroughly shellacked and baked, no shellac on outside of wire, no baking of wire.

Curve 57, 1,000 ohms, same kind of wire wound on similar wood spool, latter boiled in paraffin, no paraffin on wire, no heating of wire.

Curve 77, 1,000 ohms, on wood spool, wire and spool shellacked and baked and then coated with paraffin.

Curve 25, 1,000 ohms, on wood spool, wire shellacked and baked, and coil then sealed in a test tube by means of a cork and hot paraffin.

Curve 43, 1,000 ohms, on shellacked wood spool (several coats), wire shellacked and baked after winding. Unifilar winding.

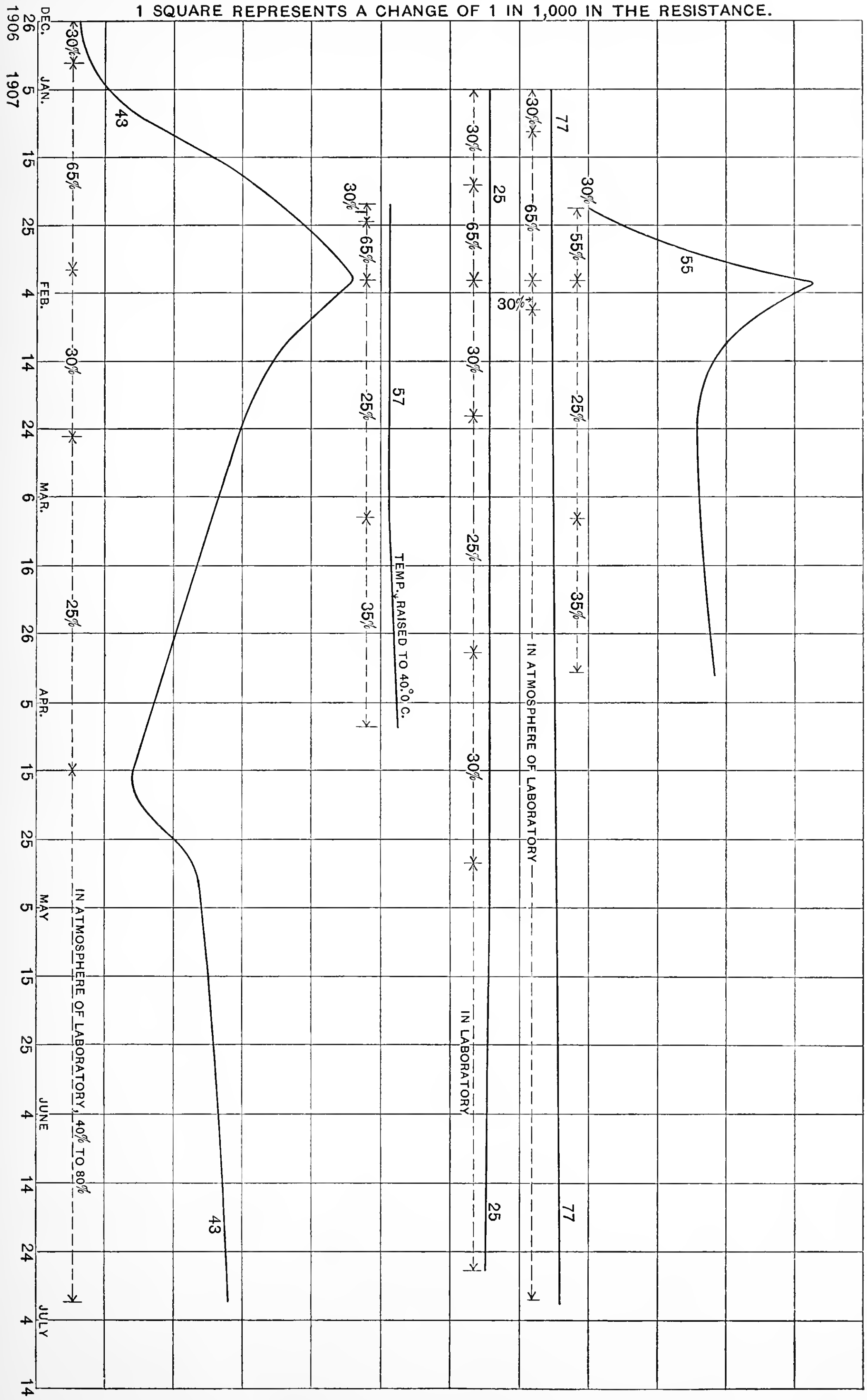

Fig. 6.—*Differences in behavior of coils wound on wood spools.*

(For explanation of curves see opposite page.)

maximum of February. As the humidity in the laboratory atmosphere in Washington often goes above 70 per cent in summer (unless the air is artificially dried), it will be seen that this coil would be very unreliable as a standard.

Fig. 6 represents five coils of 1,000 ohms each of 0.1-mm manganin wire, wound on wooden spools (mahogany). These curves are drawn to a different vertical scale from that used before, one space representing a change *ten times as great* as before. Curve 43 represents a coil which was given several coats of shellac and baked in the usual manner, the spool as well as the wire being thoroughly shellacked. Curve 55 represents a coil in which the spool was thoroughly shellacked, but the wire was not shellacked nor baked after winding. Curve 57 represents a coil wound on a similar wood spool that had been thoroughly paraffined, but the wire neither paraffined nor heated after winding. Curve 77 represents a coil on a shellacked wood spool, the wire shellacked and baked as usual and then dipped in melted paraffin. Curve 25 represents a coil on a wood spool, shellacked and baked after winding, and sealed in a test tube (with some calcium chloride inside the tube). The last three coils, in one of which no shellac was used and in the other two the shellac was protected from the moisture of the air, have remained remarkably constant, no change more than 1 in 100,000 having occurred in several months, except in 57, which was due to heating. The first two coils, on the contrary, changed as much as 340 and 400 parts, respectively, in 100,000.

Shellacked coils may absorb sufficient moisture in a saturated atmosphere to reduce the resistance by leakage, the coils in that case showing polarization. A shellacked coil plunged in water absorbs moisture very rapidly; in one case tried, the resistance of a coil of 1,000 ohms decreased about 50 ohms in a short time, showing polarization strongly. On the other hand, some paraffined coils submerged in water an hour did not change more than 1 part in 100,000, if at all. These coils were from a box by an English maker and had been in use for over four years. This shows that the paraffin coating had not become cracked or defective in use. Such coils kept submerged in water do indeed absorb moisture and finally become polarized, but this is under very extreme conditions. The shellacked coils of a Wheatstone bridge, potentiometer, or other

resistance apparatus may be dipped in melted paraffin and so be protected from moisture. A high grade of paraffin should be used—that is, paraffin of high melting point, free from dirt and acid. The paraffin coating, of course, slightly increases the lag of temperature of the coils when the temperature of the room is changing, but the increased error due to this would probably not be a hundredth part of the error that may be due to absorption of moisture.

Since a small and inexpensive coil sealed in a tube or covered by paraffin has a very constant resistance, one may possess a number of such working standards of resistance with very slight expense or trouble, and may have them compared at a standardizing laboratory more frequently than bulkier and more expensive standards. We do not recommend paraffining resistance standards of precision, but rather using such shellacked or varnished coils as have proved constant when sealed from the atmosphere. We are developing some new forms of sealed standards which have proved to be very constant during the few months they have been under observation. They will be described and the results obtained in measuring them given in the near future.

EFFECT OF CLIMATE.

Since the above was in type Drs. Jaeger and Lindeck have called attention[4] to the unfavorable climate of Washington as explaining the relatively large seasonable changes observed here in shellac-covered resistances. One of us has recently published[5] the results of an examination of the question of differences of climate between London, Berlin, and Washington, which seems to explain, in a large measure at least, why the changes observed in Washington are so much greater than those observed in Berlin.

In order to obtain a fair comparison between the atmospheric humidities of the three above-named places, reference was made to the official records of the Königlich Preussischen Meteorologischen Institut,[6] the Royal Observatory, Greenwich,[7] and the United States Weather Bureau.[8] From these records the following tables were

[4] London Electrician, August 2, 1907.

[5] London Electrician, October, 1907.

[6] Deutsches Meteorologisches Jahrbuch, für 1904 and 1905.

[7] Greenwich Magnetical and Meteorological Observations, 1904 and 1905.

[8] Report of Chief of Weather Bureau, 1904–5 and 1905–6.

compiled, showing the absolute humidities (vapor pressures in millimeters of mercury) and the relative humidities for each of the four seasons of the year for the two years 1904 and 1905, for London, Berlin, and Washington. The reason for choosing these three places was, of course, that observations on standard and precision resistances have been carried on for some years past in the national laboratories located in these cities. In Berlin no appreciable changes in resistance due to humidity have been observed; in Washington serious changes due to this cause have been found, as described above; in London appreciable changes have been reported, but we are not as yet aware whether (as seems probably the case) they have been found to be chiefly due to the effect of varying atmospheric humidity.

ABSOLUTE HUMIDITY.

Pressure of Aqueous Vapor in Millimeters of Mercury.

	London			Berlin			Washington		
	1904	1905	Mean	1904	1905	Mean	1904	1905	Mean
1. Winter—Dec., Jan., Feb.	5.4	5.4	5.4	4.5	4.5	4.5	2.9	3.0	2.95
2. Spring—Mar., Apr., May	6.5	6.3	6.4	6.2	6.3	6.25	7.0	7.9	7.45
3. Summer—Jun., Jul., Aug.	9.9	10.4	10.15	9.2	11.3	10.25	14.9	16.4	15.65
4. Autumn—Sep., Oct., Nov.	7.6	7.0	7.3	7.0	7.1	7.05	8.6	9.1	8.85
Mean for the year	7.35	7.3	7.32	6.7	7.3	7.0	8.35	9.1	8.72

The values for London are the mean of twenty-four hourly observations. For Berlin they are the mean of observations at 7 a. m., 2 p. m., and 9 p. m., which represent the twenty-four-hour average

RELATIVE HUMIDITY.

	London			Berlin			Washington		
	1904	1905	Mean	1904	1905	Mean	1904	1905	Mean
1. Winter—Dec., Jan., Feb.	87	85	86	85	84	84.5	70	67.5	68.75
2. Spring—Mar., Apr., May	78	75	76.5	70	78	74	66	68	67
3. Summer—Jun., Jul., Aug.	73	75	74	59	64	61.5	72	79	75.5
4. Autumn—Sep., Oct., Nov.	84	82	83	80	84	82	76.5	77.5	77
Mean for the year	80.5	79	79.75	73.5	77.5	75.5	71.5	72.75	72.1

very closely. For Washington they are the mean of observations at 8 a. m. and 8 p. m., which represent the twenty-four-hour average approximately, being probably a little too high.

Table I gives the values of the absolute humidities and Table II the relative humidities. It will be seen that the figures are very nearly the same for the two years.

The *mean vapor pressure* for the two years is least in Berlin, being a little higher (5 per cent) in London and considerably higher (25 per cent) in Washington than in Berlin. The vapor pressure is, however, lower in Washington in winter than in London or Berlin.

The *mean relative humidity* for the two years is *lower* in Washington than in Berlin or London, due, of course, to its higher mean temperature. In summer the relative humidity is higher in Washington than Berlin, and a very little higher than in London. During the other three seasons it is appreciably lower than in Berlin or London. This is especially noticeable in winter, when both absolute and relative humidities are lower in Washington than in London or Berlin.

But as the resistances are kept in the laboratories, whereas the above measurements were made out of doors, it is necessary to consider what differences in the relative humidities existed, on the average, between the laboratories and the outside atmosphere.

In the laboratories of the Bureau of Standards the rooms are heated by a mixture of hot and tempered air, forced through a double-duct system by large blowers, the temperature of the rooms being automatically regulated (usually to about 20° or 21° C. in winter) by thermostats. In the colder weather the blowers are kept going until midnight, and started very early in the morning, so that the temperature of the laboratories is kept at about 20° C. most of the time and seldom falls below 15° at night. The result is that the relative humidity of the atmosphere in the laboratories during the three winter months probably averages not over 30 per cent (allowing for the increase of humidity due to respiration and evaporation within the laboratories). The buildings of the Reichsanstalt are probably not heated to so high a temperature, nor heated for so many hours at night, so that the mean temperature for twenty-four hours during the three winter months would be considerably lower,

whereas the absolute humidity is higher. Hence the relative humidity (for twenty-four hours) possibly averages as high as 60 per cent during the winter months (allowing as before for some evaporation within the laboratories). In the summer a laboratory is cooler in the daytime and warmer at night than the outside atmosphere, having practically the same average temperature as the outside. Hence the mean relative humidity would be nearly the same as out of doors, or between 60 and 65 per cent in Berlin. In the spring and autumn months, due to heating the buildings part of the time, the indoor humidity would be somewhat less than outside. Hence it would seem probable (always considering the average for twenty-four hours) that the mean relative humidity in the laboratories of the Reichsanstalt varies comparatively little from season to season.

In Washington, on the other hand, the average humidity in summer (even with some artificial drying during part of each day) is more than double that in winter. Thus the differences of climate and differences in the methods of heating the laboratory buildings combine to make any effects of varying moisture much greater in Washington than in Berlin, the difference in climate being as much due to the drier winter of Washington as to the damper summer.

But Berlin is probably no more a representative city in this respect than Washington; resistances are used in all kinds of climates. The value of a resistance standard or a precision box or potentiometer should, of course, not depend on the climate, nor require a climate of relatively uniform humidity to enable it to remain constant. If a resistance standard is calibrated in Berlin or Washington at 60 per cent humidity for example, its value elsewhere will be more or less according to the humidity, if the resistance is not independent of the humidity.

Drs. Jaeger and Lindeck give results of recent measurements, which show very slight variations, indeed, in a number of standard coils of various denominations up to 10,000 ohms, confirming their previous work in this respect. Whether these coils were originally selected from a larger number because of their exceptional constancy, or whether they were differently prepared from those we have been getting in recent years, or whether it is partly accidental that the humidity varied during May and June of this year so as to leave the

coils with almost exactly the same values at the end of June that they had at the end of April, we do not know.

The 1-ohm standard coils (of the Reichsanstalt form) of the Bureau of Standards have fluctuated very little in comparison with the changes in the coils of higher values, but they do vary among themselves under natural conditions by an appreciable amount, due to variations in atmospheric humidity, and these variations have been a source of serious concern to us.

The sealed standards which we have recently devised and have been studying for several months differ mainly from those now generally used (and known as the Reichsanstalt form) in being of smaller size, having closed cases which are hermetically sealed, and in having the cases permanently filled with pure oil. The resistances are thus oil immersed, and the temperature can be accurately obtained, and yet no change due to varying humidity can occur, as the thoroughly dried resistances and oil are perfectly protected from the atmosphere.

Our work tends to confirm the work of Drs. Jaeger and Lindeck, as they very properly observe, not only that manganin is very well adapted for resistance standards, but that the method of mounting the resistances and protecting them from the oxidation of the air or oil by shellac or varnish is very satisfactory, *provided they are also protected from the effects of atmospheric humidity.* This effect is certainly too great in the higher resistances in general to be safely ignored in precision work, whether in standards or in resistance boxes. If by some modification in the construction of the standards, as Drs. Jaeger and Lindeck suggest, or by sealing them from the atmosphere as we have done, the danger of change due to humidity is obviated, then they would seem to be all that could be expected of wire standards. With resistance boxes that are not to be submerged in oil, we have found a coating of paraffin over the shellac or varnish to be of value. The temperature coefficient of manganin is so small that a slight uncertainty of temperature in many cases is not material. With boxes that are to be oil immersed the coils (or at least the higher valued coils) may be separately sealed in metal tubes, or better the entire box, if properly designed, may be sealed.

It has been a mystery to us at the Bureau of Standards why the manganin standards of the Reichsanstalt remained so much more constant than those in Washington. We think the facts given above as to the probable differences in the variation of the relative humidity in the laboratories of the Reichsanstalt and the Bureau of Standards go far toward explaining the difference in the behavior of the resistances. It is also possible that, although we have supposed the resistance coils to be made exactly alike, it is partly due to some difference in their preparation.

WASHINGTON, October 4, 1907.